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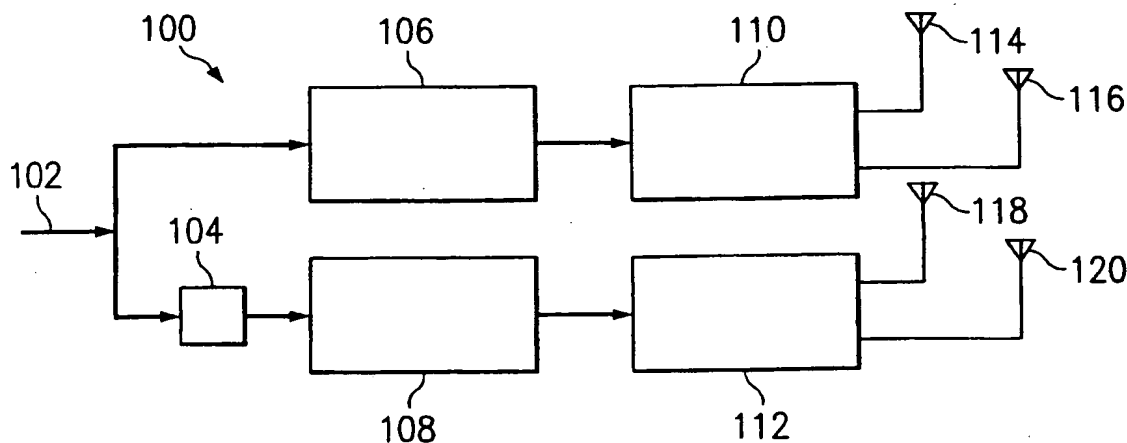
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(54) Title: SPACE-TIME CODE FOR MULTIPLE ANTENNA TRANSMISSION



(57) Abstract: A method and apparatus for space-time coding signals for transmission on multiple antennas. A received input symbol stream is transformed using a predefined transform and transmitted on a first set of N antennas. The same input symbol stream is then offset by M symbol periods to generate an offset input symbol stream. The offset input symbol stream is then transformed using the predefined transform and transmitted on a second set of N antennas. A third through Xth set of N antennas may be utilized for transmission by successively offsetting the offset input symbol stream by an additional M symbol periods for each additional set of N antennas used, before performing the transform and transmitting on the additional set of N antennas.

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SPACE-TIME CODE FOR MULTIPLE ANTENNA TRANSMISSION

FIELD OF THE INVENTION:

This invention relates to a method and apparatus for achieving transmit diversity in telecommunication systems and, more particularly, to a method and apparatus for space-time coding signals for transmission on multiple antennas.

BACKGROUND OF THE INVENTION:

As wireless communication systems evolve, wireless system design has become increasingly demanding in relation to equipment and performance requirements. Future wireless systems, which will be third and fourth generation systems compared to the first generation analog and second generation digital systems currently in use, will be required to provide high quality high transmission rate data services in addition to high quality voice services. Concurrent with the system service performance requirements will be equipment design constraints, which will strongly impact the design of mobile terminals. The third and fourth generation wireless mobile terminals will be required to be smaller, lighter, more power-efficient units that are also capable of providing the sophisticated voice and data services required of these future wireless systems.

Time-varying multi-path fading is an effect in wireless systems whereby a transmitted signal propagates along multiple paths to a receiver causing fading of the received signal due to the constructive and destructive summing of the signals at the receiver. Several methods are known for overcoming the effects of multi-path fading, such as time interleaving with error correction coding, implementing frequency diversity by utilizing spread spectrum techniques, or transmitter power control techniques. Each of these techniques, however, has drawbacks in regard to use for third and fourth generation wireless systems. Time interleaving may introduce unnecessary delay, spread spectrum techniques may require large bandwidth allocation to overcome a large coherence bandwidth, and power control techniques may require higher transmitter power than is desirable for sophisticated receiver-to-transmitter

feedback techniques that increase mobile terminal complexity. All of these drawbacks have negative impact on achieving the desired characteristics for third and fourth generation mobile terminals.

Antenna diversity is another technique for overcoming the effects of multi-path fading in wireless systems. In diversity reception, two or more physically separated antennas are used to receive a signal, which is then processed through combining and switching to generate a received signal. A drawback of diversity reception is that the physical separation required between antennas may make diversity reception impractical for use on the forward link in the new wireless systems where small mobile terminal size is desired. A second technique for implementing antenna diversity is transmit diversity. In transmit diversity a signal is transmitted from two or more antennas and then processed at the receiver by using maximum likelihood sequence estimator (MLSE) or minimum mean square error (MMSE) techniques. Transmit diversity has more practical application to the forward link in wireless systems in that it is easier to implement multiple antennas in the base station than in the mobile terminal.

Transmit diversity for the case of two antennas is well studied. Alamouti has proposed a method of transmit diversity for two antennas that offers second order diversity for complex valued signals. S. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," *IEEE Journal on Selected Areas of Communications*, pp. 1451-1458, October 1998. The Alamouti method involves simultaneously transmitting two signals from two antennas during a symbol period. During one symbol period, the signal transmitted from a first antenna is denoted by s_0 and the signal transmitted from the second antenna is denoted by s_1 . During the next symbol period, the signal $-s_1^*$ is transmitted from the first antenna and the signal s_0^* is transmitted from the second antenna, where $*$ is the complex conjugate operator. The Alamouti method may also be done in space and frequency coding. Instead of two adjacent symbol periods, two orthogonal Walsh codes may be used to realize space-frequency coding.

Extension of the Alamouti method to more than two antennas is not straightforward. Tarokh et al. have proposed a method using rate = $\frac{1}{2}$, and $\frac{3}{4}$ SpaceTime Block codes for transmitting on three and four antennas using complex signal constellations. V. Tarokh, H. Jafarkhani, and A. Calderbank,
5 *"Space-Time Block Codes from Orthogonal Designs," IEEE Transactions on Information Theory, pp. 1456-1467, July 1999.* This method has a disadvantage in a loss in transmission rate and the fact that the multi-level nature of the ST coded symbols increases the peak-to-average ratio requirement of the transmitted signal and imposes stringent requirements on
10 the linear power amplifier design. Other methods proposed include a rate = 1, orthogonal transmit diversity (OTD) + space-time transmit diversity scheme (STTD) four antenna method. L. Jalloul, K. Rohani, K. Kuchi, and J. Chen, *"Performance Analysis of CDMA Transmit Diversity Methods," Proceedings of IEEE Vehicular Technology Conference, Fall 1999,* and M. Harrison, K. Kuchi,
15 *"Open and Closed Loop Transmit Diversity at High Data Rates on 2 and 4 Elements," Motorola Contribution to 3GPP-C30-19990817-017.* This method requires an outer code and offers second order diversity due to the STTD block (Alamouti block) and a second order interleaving gain from use of the OTD block. The performance of this method depends on the strength of the outer
20 code. Since this method requires an outer code, it is not applicable to uncoded systems. For the case of rate = $\frac{1}{3}$ convolutional code, the performance of the OTD + STTD method and the Tarokh rate = $\frac{3}{4}$ method ST block code methods are about the same.

SUMMARY OF THE INVENTION

25 The present invention presents a method and apparatus for space-time coding signals for transmission on multiple antennas. In the method and apparatus, a received input symbol stream is transformed using a predefined transform and transmitted on a first set of N antennas. The same input symbol stream is then offset in time by M symbol periods to generate an offset input
30 symbol stream. The offset input symbol stream may be offset so as to lead or lag the input symbol stream. The offset input symbol stream is then

transformed using the predefined transform and transmitted on a second set of N antennas. A third through X^{th} set of N antennas may be utilized for transmission by successively offsetting the offset input symbol stream by an additional M symbol periods for each additional set of N antennas used, before
5 performing the transform and transmitting on the additional set of N antennas. The transform may be applied in either the time domain or Walsh code domain.

At the receiver, the transmitted symbols may be recovered using a maximum likelihood sequence estimator (MLSE) decoder implemented with the Viterbi algorithm with a decoding trellis according to the transmitter.

10 In an embodiment, 4 antennas are used for transmission. Every 2 input symbols in a received input symbol stream are transformed in the time domain by an Alamouti transform and the result is transmitted on antennas 1 and 2 during the time of two symbol periods. The received input symbol stream is also delayed for two symbol periods, and this delayed input symbol stream is
15 input to an Alamouti transform where every two symbols are transformed and the delayed result is transmitted on antennas 3 and 4 during the time of two symbol periods. The transmitted signal may be received and decoded using an MLSE receiver. The method and apparatus provides diversity of order four and outperforms other proposed extensions of the Alamouti method to more than
20 two antennas by approximately $\frac{1}{2}$ to 1 dB for uncoded transmissions.

In an alternative embodiment using 4 antennas, every 2 input symbols in a received input symbol stream are transformed in the Walsh code domain. The Alamouti coded symbols are transmitted on two orthogonal Walsh codes, W1 and W2 simultaneously on antennas 1 and 2. Both W1 and W2 span two
25 symbol periods, which maintains the transmission rate at two symbol periods. The received input symbol stream is also delayed for two symbol periods and the Alamouti transform is also applied in the Walsh code domain to the delayed input symbol stream. This delayed result is transmitted on antennas 3 and 4 during the time of two symbol periods.

30 In a further alternative embodiment using 8 antennas for transmission, a rate = $\frac{3}{4}$ ST block code is combined with a 4 symbol delay. Every three

symbols in an input symbol stream are transformed by the ST block code and transmitted on antennas 1-4. The received input symbol stream is also delayed for four symbol periods, and this delayed input symbol stream is input to the ST block code transform where every three symbols are transformed and the
5 delayed result is transmitted on antennas 4-8 during the time of four symbol periods.

BRIEF DESCRIPTION OF THE FIGURES:

FIG. 1 shows a block diagram of portions of a transmitter according to an embodiment of the invention;

10 FIG. 2 shows a block diagram of portions of a receiver according to an embodiment of the invention;

FIG. 3 shows a trellis structure used to process signals in the receiver of FIG. 2;

15 FIG. 4 shows a block diagram of portions of a transmitter according to an alternative embodiment of the invention; and

FIG. 5 shows a block diagram of portions of a transmitter according to a further alternative embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION:

Referring now to FIG. 1, therein is illustrated a block diagram of portions
20 of a transmitter 100 according to an embodiment of the invention. Transmitter 100 includes input 102, offset block 104, transform block 106, transform block 108, spread, filter and modulate (SFM) block 110, spread, filter and modulate (SFM) block 112, antenna 114, antenna 116, antenna 118 and antenna 120. Transmitter 100 may be implemented into any type of transmission system that
25 transmits coded or uncoded digital transmissions over a radio interface.

In the embodiment of FIG. 1, transmitter 100 receives an input symbol stream $X(t)$ at input 102. $X(t)$ is split into two identical symbol streams, with one symbol stream $X(t)$ being input to transform block 106 and a second

identical symbol stream $X(t)$ being input to offset block 104. Offset block 104 causes a 2 symbol period delay in the second symbol stream and then the delayed second symbol stream is input to transform block 108. Every two symbols S_1 and S_2 are processed in transform block 106 using the Alamouti method and the output of the transform is transmitted on antenna 114 and antenna 116. The input signal may be complex valued and of arbitrary constellation size. The Alamouti transformation performed in transform block 106 can be written in a matrix form as shown below:

$$\begin{bmatrix} S_1 & S_2 \\ -S_2^* & S_1^* \end{bmatrix}$$

Equation 1

The rows in the matrix indicate the antenna the symbol is transmitted on, and the columns indicate the instant they are transmitted. Symbols S_1 and S_2 are transmitted on antenna 114 and antenna 116 at instants t_1 and t_2 , respectively.

The second identical symbol stream $X(t)$ input to offset block 104 is offset by two symbol periods and transformed in transform block 108 using the Alamouti transformation as shown below:

$$\begin{bmatrix} Sd_1 & Sd_2 \\ -Sd_2^* & Sd_1^* \end{bmatrix}$$

Equation 2

The output of the transform from transform block 108 is then transmitted on antenna 118 and antenna 120. The transmitted signal as it will be received during the time period $(0, t_1)$ can be written as follows:

$$r(t_1) = \sqrt{\frac{E_c}{4}} \left[S_1 \alpha_1 - S_2^* \alpha_2 + S_{d1} \alpha_3 - S_{d2}^* \alpha_4 \right] + n(t_1)$$

Equation 3

and, for the time duration (t_1, t_2) as,

$$r(t2) = \sqrt{\frac{E_c}{4}} \left[S_2 \alpha_1 + S_1^* \alpha_2 + S_{d2} \alpha_3 + S_{d1}^* \alpha_4 \right] + n(t2)$$

Equation 4

where S_{d1} and S_{d2} are the transmitted symbols on the delayed branch and $n(t)$ is the additive white Gaussian noise.

- 5 The transmitted signal power E_c may be evenly distributed across the four antennas and the channel coefficients α may be modelled as complex Gaussian.

This received signal can be decoded using an MLSE receiver. Referring now to FIG. 2, therein is shown a receiver 200 according to an embodiment of the invention. Receiver 200 includes antenna 202, filter, despread and demodulate block 204, processor block 206, and output 208.

In the embodiment, receiver 200 receives the transmitted signal $r(t)$ at antenna 202, and filters, despreads and demodulates the signal in filter, despread and demodulate block 204. Processor block 206 then decodes the sequence that minimizes the Euclidian distance D between the transmitted and received signals and outputs the sequence at output 208 according to the following:

$$\begin{aligned} D &= \|r(t) - (x(t) + x(t - 2T))\| \\ &= \|r(t1) - (S_1 \alpha_1 - S_2^* \alpha_2 + S_{d1} \alpha_3 - S_{d2}^* \alpha_4)\| + \|r(t2) - (S_2 \alpha_1 + S_1^* \alpha_2 + S_{d2} \alpha_3 + S_{d1}^* \alpha_4)\| \end{aligned}$$

Equation 5

- 20 Further optimization of the branch metrics can be obtained with the following simplification. Using the equations,

$$\tilde{r}(t1) = r(t1) - (S_1 \alpha_1 - S_2^* \alpha_2)$$

Equation 6

$$\tilde{r}(t2) = r(t2) - (S_2 \alpha_1 + S_1^* \alpha_2)$$

Equation 7

the following metric can be obtained:

$$D^2 = \|\tilde{r}(t1) - (S_{d1}\alpha3 - S_{d2}^*\alpha4)\|^2 + \|\tilde{r}(t2) - (S_{d2}\alpha3 + S_{d1}^*\alpha4)\|^2$$

Equation 8

5 This may be further simplified as:

$$D^2 = \|\tilde{r}(t1)(\alpha3)^* + \tilde{r}(t2)^*\alpha4 - S_{d1}\|^2 + \|\tilde{r}(t1)(\alpha4)^* - \tilde{r}(t2)^*\alpha3 + S_{d2}^*\|^2$$

Equation 9

Symbols S_{d1}, S_{d2} may be found separately. In the simplification given by equation 9, only the values S_{d1} and S_{d2} need to be modified at each
10 computation stage. This reduces the number of multiplications in the calculation.

The input to the Viterbi decoder is the sampled received signal observed over "n" time epochs or n symbol periods, where n= 2 for 4 antenna ST codes. The state transitions in the Viterbi decoder occur every "n" time
15 epochs.

Referring now to FIG. 3, therein is shown a trellis structure 300 used to process the ST code of the received signal in receiver 200, according to an embodiment of the invention. Trellis structure 300 is the binary phase shift keying (BPSK) trellis diagram for a 4 antenna space-time (ST) code. Trellis 300
20 can be described using the following state labelling:

$$\text{Next state} = \text{input symbols } (S_1, S_2)$$

Equation 10

$$\text{Output} = \{\text{previous state, input symbols}\} = \{(S_{d1}, S_{d2}), (S_1, S_2)\}$$

Equation 11

The number of states in the trellis 300 is given by M^2 where M is the signal constellation size. The total number of states shown in trellis 300 is 4. Trellis 300 may be decoded using the Viterbi algorithm. FIG. 3 shows the bpsk case. Other modulation may be used in alternative embodiments. Generally,
5 for the case of a 4-antenna ST code, the decoder has to remember all possible 2 previous symbols (i.e., 4 states for bpsk, and 16 states for qpsk, 64 states for 8-psk and so on) at each state.

Referring now to FIG. 4, therein are shown portions of a transmitter according to an alternative embodiment of the invention. FIG. 4. shows
10 transmitter 400, which includes input 402, offset block 404, space-time spreading (STS) transform block 406, STS transform block 408, filter and modulate block 420, filter and modulate block 412 and antennas 414, 416, 418 and 420. In transmitter 400, the Alamouti transformation is applied in Walsh code domain instead of time domain. The Alamouti coded symbols are
15 transmitted on two orthogonal Walsh codes W1, W2 simultaneously. Both W1 and W2 span two symbol periods in this case maintaining the total transmission rate. This method is known as space-time spreading (STS) [7]. A delayed copy of the input signal is STS transformed again and transmitted via the other two antennas.

20 In the embodiment of FIG. 4, transmitter 400 receives an input symbol stream $X(t)$ at input 402. $X(t)$ is split into two identical symbol streams, with one symbol stream $X(t)$ being input to transform block 406 and a second identical symbol stream $X(t)$ being input to offset block 404. Offset block 404 causes a 2 symbol period delay in the second symbol stream and then the
25 delayed second symbol stream is input to transform block 408. Every two symbols S1 and S2 are processed in transform block 406 using the Alamouti method and the output of the transform is transmitted on antenna 414 and antenna 416. The input signal may be complex valued and of arbitrary constellation size. The Alamouti transformation performed in STS transform
30 block 406 can be written in a matrix form as shown below:

$$\begin{bmatrix} S_1 W_1 & S_2 W_2 \\ -S_2^* W_1 & S_1^* W_2 \end{bmatrix}$$

Equation 12

The rows in the matrix indicate the antenna on which the symbol is transmitted. The symbols S1 and S2 are transmitted simultaneously on antenna 414 during the same two symbol periods in which the symbols $-S_2^*$ and S_1^* are transmitted simultaneously on antenna 416.

The second identical symbol stream $X(t)$ input to offset block 404 is delayed by two symbol periods and transformed in transform block 408 using the Alamouti transformation as shown below:

$$\begin{bmatrix} Sd_1 W_1 & Sd_2 W_2 \\ -Sd_2^* W_1 & Sd_1^* W_2 \end{bmatrix}$$

Equation 13

The rows in the matrix indicate the antenna on which the symbol is transmitted. The symbols Sd1 and Sd2 are transmitted simultaneously on antenna 418 during the same two symbol periods in which the symbols $-Sd_2^*$ and Sd_1^* are transmitted simultaneously on antenna 420.

A receiver for the embodiment of the transmitter of FIG. 4 may be implemented in the same manner as the receiver of FIG. 2, with the filter, despread and demodulate block 204 modified to receive the Alamouti coded symbols that are transmitted simultaneously on the Walsh codes W1 and W2.

Various alternative embodiments of the invention are possible. For example, in the case of three transmit antennas, the output of any two of the Alamouti/STS branches can be mapped to the same antenna to obtain a diversity gain of order three. Also, for 6 and 8 antennas the given method can be generalized by using Alamouti transform block combined with 3 and 4 delay diversity branches, respectively.

A further alternative embodiment may also be used for 8 transmit antennas. Referring now to FIG. 5, therein is illustrated a block diagram of portions of a transmitter 500 according to a further alternative embodiment of the invention. Transmitter 500 includes input 502, offset block 504, transform
5 block 506, transform block 508, spread, filter and modulate (SFM) block 510, spread, filter and modulate (SFM) block 512, antenna 514, antenna 516, antenna 518, antenna 520, antenna 522, antenna 524, antenna 526 and antenna 528. Transmitter 500 may be implemented into any type of transmission system that transmits coded or uncoded digital transmissions over
10 a radio interface.

In the embodiment of FIG. 5, transmitter 500 receives an input symbol stream $X(t)$ at input 502. $X(t)$ is split into two identical symbol streams, with one symbol stream $X(t)$ being input to transform block 506, and a second identical symbol stream $X(t)$ being input to offset block 504. Offset block 504
15 causes a 4 symbol period delay in the second symbol stream and then the delayed second symbol stream is input to transform block 508. Every three symbols S_1 , S_2 and S_3 are processed in transform block 506 using a $\frac{3}{4}$ rate block code transform and the output of transform block 506 is transmitted on antennas 514, 516, 518 and 520. The $\frac{3}{4}$ rate block code may be as described
20 in the paper by V. Tarokh, H. Jafarkhani, and A. Calderbank, "Space-Time Block Orthogonal Codes from Orthogonal Designs," *IEEE Transactions on Information Theory*, pp. 1456-1467, July 1999. The delayed second input symbol stream is processed in block 508 using the same $\frac{3}{4}$ rate block code transform and the output of transform block 508 is transmitted on antennas 522,
25 524, 526 and 528. The input signal may be complex valued and of arbitrary constellation size.

The $\frac{3}{4}$ rate ST block code is given by the following transformation.

$$\begin{bmatrix} s_1 & s_2 & s_3 & 0 \\ -s_2^* & s_1^* & 0 & -s_3 \\ -s_3^* & 0 & s_1^* & s_2 \\ 0 & s_3^* & -s_2^* & s_1 \end{bmatrix}$$

Equation 14

The trellis structure for the 8-antenna ST code can be described using the following state labelling.

5 Next state = input symbols (s_1, s_2, s_3)

Equation 15

Output label = {previous state, input symbols} = $\{(s_{d1}, s_{d2}, s_{d3}), (s_1, s_2, s_3)\}$

Equation 16

10 A receiver for the embodiment of the transmitter of FIG. 5 may be implemented in the same manner as the receiver of FIG. 2, with the filter, despread and demodulate block 204 modified to receive the $\frac{3}{4}$ rate block code symbols. It is assumed that the Viterbi decoder has knowledge of the estimated channel coefficients. For the 8-antenna case of FIG. 5, the decoder has to remember all possible 3 previous symbols at each state (i.e., M^3 states for M-psk).

15 The branch metrics given for the 4-antenna ST code for FIG.1 may be generalized to the 8-antenna case.

20 The described and other embodiments could be implemented in systems using any type of multiple access technique, such as time division multiple access (TDMA), code division multiple access (CDMA), frequency division multiple access (FDMA), orthogonal frequency division multiple access (OFDM), or any combination of these, or any other type of access technique. This could also include systems using any type of modulation to encode the digital data.

Thus, although the method and apparatus of the present invention has been illustrated and described with regard to presently preferred embodiments thereof, it will be understood that numerous modifications and substitutions may be made to the embodiments described, and that numerous other embodiments
5 of the invention may be implemented without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1 1. A method for transmitting a signal from a plurality of antennas,
2 said method comprising the steps of:
3 receiving a first input symbol stream at a transmitter;
4 offsetting said first input symbol stream to generate a second input
5 symbol stream, wherein said second input symbol stream is offset
6 from said first input symbol stream by at least two symbol periods;
7 performing a first transform on at least two symbols of said first
8 input symbol stream over a time period to generate a first transform
9 result;
10 performing a second transform on at least two symbols of said
11 second input symbol stream, substantially simultaneously over said
12 time period, to generate a second transform result; and
13 transmitting, substantially simultaneously, said first transform result
14 on a first at least one antenna and said second transform result on
15 a second at least one antenna.

1 2. The method of claim 1, wherein said step of performing a first
2 transform and said step of performing a second transform each comprise the
3 step of performing an Alamouti transform.

1 3. The method of claim 2, wherein said step of offsetting comprises
2 offsetting said first input symbol stream to generate a second input symbol
3 stream, wherein said second input symbol stream is offset from said first input
4 symbol stream by two symbol periods, and wherein said step of performing a
5 first transform and said step of performing a second transform each comprise
6 performing an Alamouti transform on two symbols over a time period of two
7 symbol periods.

1 4. The method of claim 3, wherein said step of transmitting
2 comprises transmitting said first transform result on a first and second antenna
3 and said second transform result on a third and fourth antenna.

1 5. The method of claim 2, wherein said Alamouti transform is
2 performed in the time domain.

1 6. The method of claim 5, wherein said step of offsetting comprises
2 delaying said first input symbol stream to generate a second input symbol
3 stream, wherein said second input symbol stream is offset from said first input
4 symbol stream by two symbol periods, and wherein said step of performing a
5 first transform and said step of performing a second transform each comprise
6 performing an Alamouti transform on two symbols over a first time period of two
7 symbol periods, and said step of transmitting comprises transmitting said first
8 transform result on a first and second antenna and said second transform result
9 on a third and fourth antenna over a second time period of two symbols,
10 wherein consecutive first and second transform symbols are transmitted from
11 each antenna during a first and second portion, respectively, of said second
12 time period of two symbols.

1 7. The method of claim 2, wherein said Alamouti transform is
2 performed in the Walsh code domain.

1 8. The method of claim 7, wherein said step of offsetting comprises
2 delaying said first input symbol stream to generate a second input symbol
3 stream, wherein said second input symbol stream is offset from said first input
4 symbol stream by two symbol periods, and wherein said step of performing a
5 first transform and said step of performing a second transform each comprise
6 performing an Alamouti transform on two symbols over a first time period of two
7 symbol periods, and said step of transmitting comprises transmitting said first
8 transform result on a first and second antenna and said second transform result
9 on a third and fourth antenna over a second time period of two symbols,
10 wherein first and second transform symbols are simultaneously transmitted from
11 each antenna over said second time period of two symbols.

1 9. The method of claim 1, wherein said step of performing a first
2 transform and said step of performing a second transform each comprise the
3 step of performing 3/4 block code transform.

1 10. The method of claim 9, wherein said step of offsetting comprises
2 delaying said first input symbol stream to generate a second input symbol
3 stream, wherein said second input symbol stream is offset from said first input
4 symbol stream by four symbol periods, and wherein said step of performing a
5 first transform and said step of performing a second transform each comprise
6 performing 3/4 block code transform on three symbols over a time period of four
7 symbol periods.

1 11. The method of claim 10, wherein said step of transmitting
2 comprises transmitting said first transform result on a first, second, third and
3 fourth antenna and said second transform result on a fifth, sixth, seventh and
4 eighth antenna.

1 12. The method of claim 11, wherein said step of offsetting comprises
2 delaying said first input symbol stream to generate a second input symbol
3 stream, wherein said second input symbol stream is offset from said first input
4 symbol stream by four symbol periods, and wherein said step of performing a
5 first transform and said step of performing a second transform each comprise
6 performing 3/4 block code transform on three symbols over a first time period of
7 four symbol periods, and said step of transmitting comprises transmitting said
8 first transform result on a first, second, third and fourth antenna and said
9 second transform result on a fifth, sixth, seventh and eighth antenna over a
10 second time period of four symbols, wherein consecutive first, second, third and
11 fourth transform symbols are transmitted from each antenna during a first,
12 second, third and fourth period, respectively, in said second time period of four
13 symbols.

1 13. An apparatus for transmitting a signal from a plurality of antennas,
2 said apparatus comprising:

3 offset means for offsetting said first input symbol stream to
4 generate a second input symbol stream, wherein said second input
5 symbol stream is offset from said first input symbol stream by at
6 least two symbol periods;

7 first transform means for performing a first transform on at least two
8 symbols of said first input symbol stream over a time period to
9 generate a first transform result;

10 second transform means for performing a second transform on at
11 least two symbols of said second input symbol stream, substantially
12 simultaneously over said time period, to generate a second
13 transform result;

14 a first at least one antenna and a second at least one antenna; and

15 transmitter means for transmitting, substantially simultaneously,
16 said first transform result on said first at least one antenna and said
17 second transform result on said second at least one antenna.

1 14. The apparatus of claim 13, wherein said first transform means for
2 performing a first transform and said second transform means for performing a
3 second transform each comprise means for performing an Alamouti transform.

1 15. The apparatus of claim 14, wherein said offset means comprises
2 means for offsetting said first input symbol stream to generate a second input
3 symbol stream, wherein said second input symbol stream lags said first input
4 symbol stream by two symbol periods, and wherein said first transform means
5 and said second transform means each comprise means for performing an
6 Alamouti transform on two symbols over a time period of two symbol periods.

1 16. The apparatus of claim 15, wherein said transmitter means
2 comprises means for transmitting said first transform result on said first and
3 second antenna and said second transform result on said third and fourth
4 antenna.

1 17. The apparatus of claim 16, wherein said first transform means and
2 said second transform means perform said Alamouti transform in the time
3 domain.

1 18. The apparatus of claim 17, wherein said offset means comprises
2 means for offsetting said first input symbol stream to generate a second input
3 symbol stream, wherein said second input symbol stream is offset from said first
4 input symbol stream by two symbol periods, and wherein said first transform
5 means and said second transform means each comprise means for performing
6 an Alamouti transform on two symbols over a time period of two symbol
7 periods, and said transmitter means comprise means for transmitting said first
8 transform result on said first and second antenna and said second transform
9 result on said third and fourth antenna over a second time period of two
10 symbols, wherein consecutive first and second transform symbols are
11 transmitted from each antenna during a first and second portion, respectively, of
12 said second time period of two symbols.

1 19. The apparatus of claim 18, wherein said first transform means and
2 said second transform means perform said Alamouti transform in the Walsh
3 code domain.

1 20. The apparatus of claim 19, wherein said offset means comprises
2 means for delaying said first input symbol stream to generate a second input
3 symbol stream, wherein said second input symbol stream is offset from said first
4 input symbol stream by two symbol periods, and wherein said first transform
5 means and said second transform means each comprise means for performing
6 an Alamouti transform on two symbols over a first time period of two symbol
7 periods, and said transmitter means comprises means for transmitting said first
8 transform result on said first and second antenna and said second transform
9 result on said third and fourth antenna over a second time period of two
10 symbols, wherein first and second transform symbols are simultaneously
11 transmitted from each antenna over said second time period of two symbols.

1 21. The apparatus of claim 20, wherein said first transform means for
2 performing a first transform and said second transform means for performing a

3 second transform each comprise means for performing a 3/4 block code
4 transform.

1 22. The apparatus of claim 21, wherein said offset means comprises
2 means for offsetting said first input symbol stream to generate a second input
3 symbol stream, wherein said second input symbol stream is offset from said first
4 input symbol stream for four symbol periods, and wherein said first transform
5 means and said second transform means each comprise means for performing
6 a 3/4 block code transform on three symbols over a time period of four symbol
7 periods.

1 23. The apparatus of claim 22, wherein said first at least one antenna
2 comprises a first, second, third and fourth antenna, and said second at least
3 one antenna comprises a fifth, sixth, seventh and eighth antenna.

1 24. The apparatus of claim 23, wherein said offset means comprises
2 means for offsetting said first input symbol stream to generate a second input
3 symbol stream, wherein said second input symbol stream is offset from said first
4 input symbol stream by four symbol periods, and wherein said first transform
5 means and said second transform means each comprise means for performing
6 a 3/4 block code transform on three symbols over a time period of four symbol
7 periods, and transmitter means comprises means for transmitting said first
8 transform result on said first, second, third and fourth antenna and said second
9 transform result on said fifth, sixth, seventh and eighth antenna over a second
10 time period of four symbols, wherein consecutive first, second, third and fourth
11 transform symbols are transmitted from each antenna during a first, second,
12 third and fourth period, respectively, of said second time period of four symbols.

1 25. A method for receiving a signal transmitted from a plurality of
2 antennas at a transmitter, said method comprising the steps of:

3 receiving a signal, wherein said signal includes a first set of
4 symbols which were input to a first transform at the transmitter and
5 transmitted on a first at least one antenna, and a second set of
6 symbols which were substantially simultaneously input to a second

transform at the transmitter and transmitted on a second at least one antenna, wherein said second set of symbols comprises said first set of symbols offset by at least two symbol periods; and decoding said signal using a Viterbi decoder.

26. The method of claim 25, wherein said first and second transforms comprise Alamouti transforms.

27. The method of claim 26, wherein said second set of symbols is offset from said first set of symbols by two symbol periods, and wherein said first and second Alamouti transforms are performed on two consecutive symbols over a time period of the symbol periods.

28. An apparatus for receiving a signal transmitted from a plurality of antennas at a transmitter, said apparatus comprising:

a receiver for receiving the signal; and

a decoder coupled to said receiver, said decoder for decoding the signal, wherein said signal includes a first set of symbols which were input to a first transform at the transmitter and transmitted on a first at least one antenna, and a second set of symbols which were substantially simultaneously input to a second transform at the transmitter and transmitted on a second at least one antenna, wherein said second set of symbols comprises said first set of symbols offset by at least two symbol periods.

29. The apparatus of claim 28, wherein said first and second transforms comprises Alamouti transforms.

30. The apparatus of claim 29, wherein said second set of symbols is offset from said first set of symbols by the symbol periods, and wherein said first and second Alamouti transforms are performed on two consecutive symbols over a time period of two symbol periods.

1/2

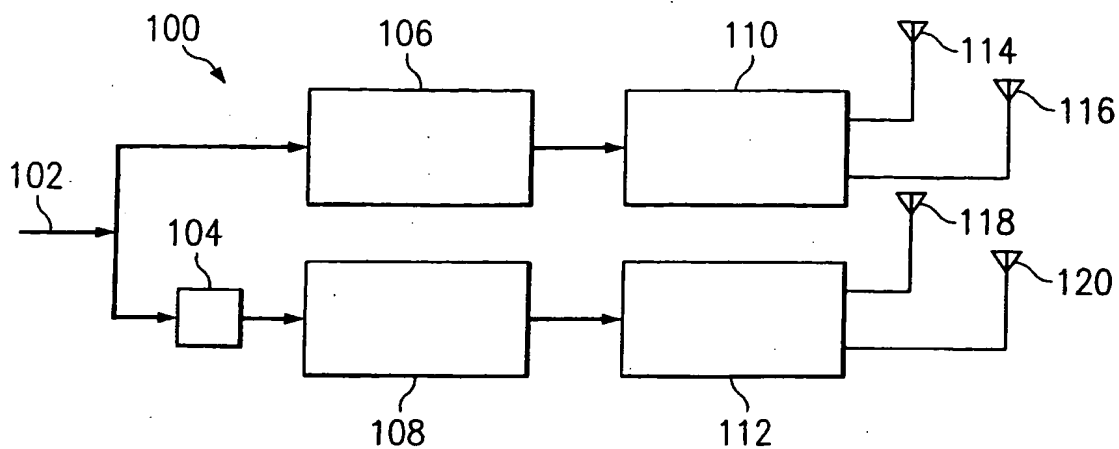


FIG. 1

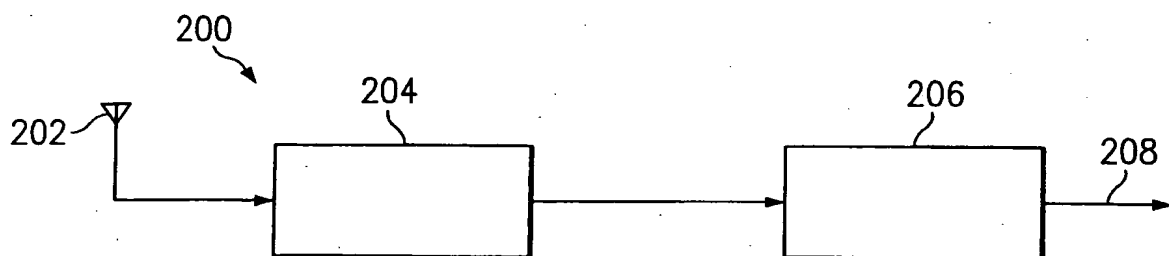


FIG. 2

STATE*	OUTPUT SYMBOLS (ANT.1, ANT.2)			
	0	1	2	3
0	(0,0)	(0,1)	(0,2)	(0,3)
1	(1,0)	(1,1)	(1,2)	(1,3)
2	(2,0)	(2,1)	(2,2)	(2,3)
3	(3,0)	(3,1)	(3,2)	(3,3)

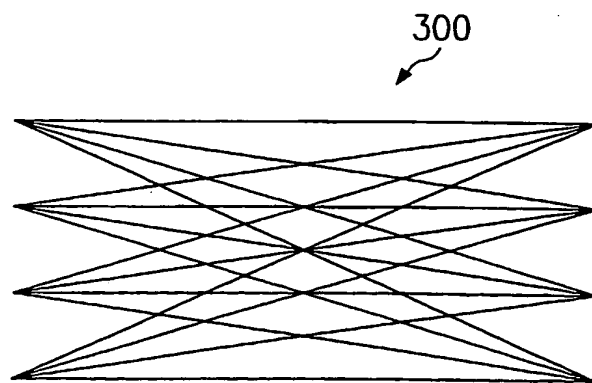


FIG. 3

2/2

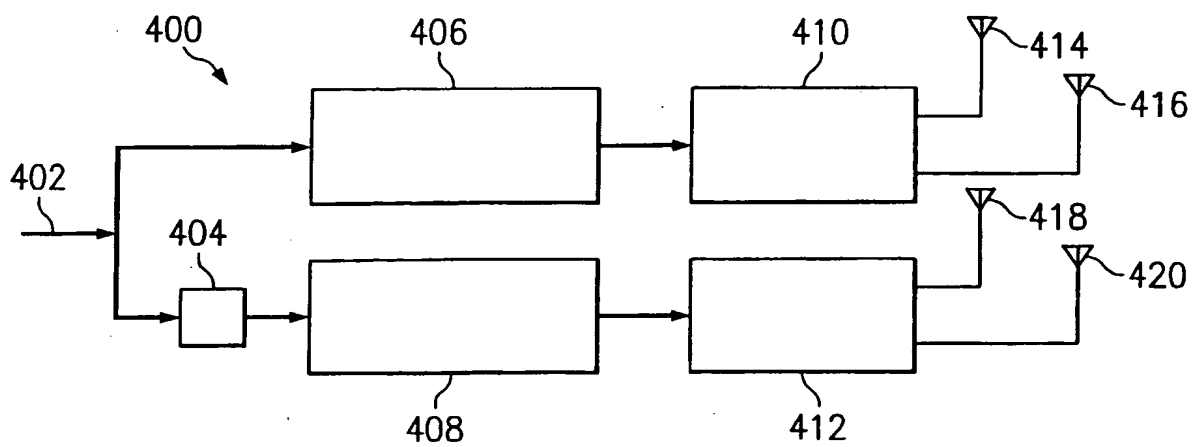


FIG. 4

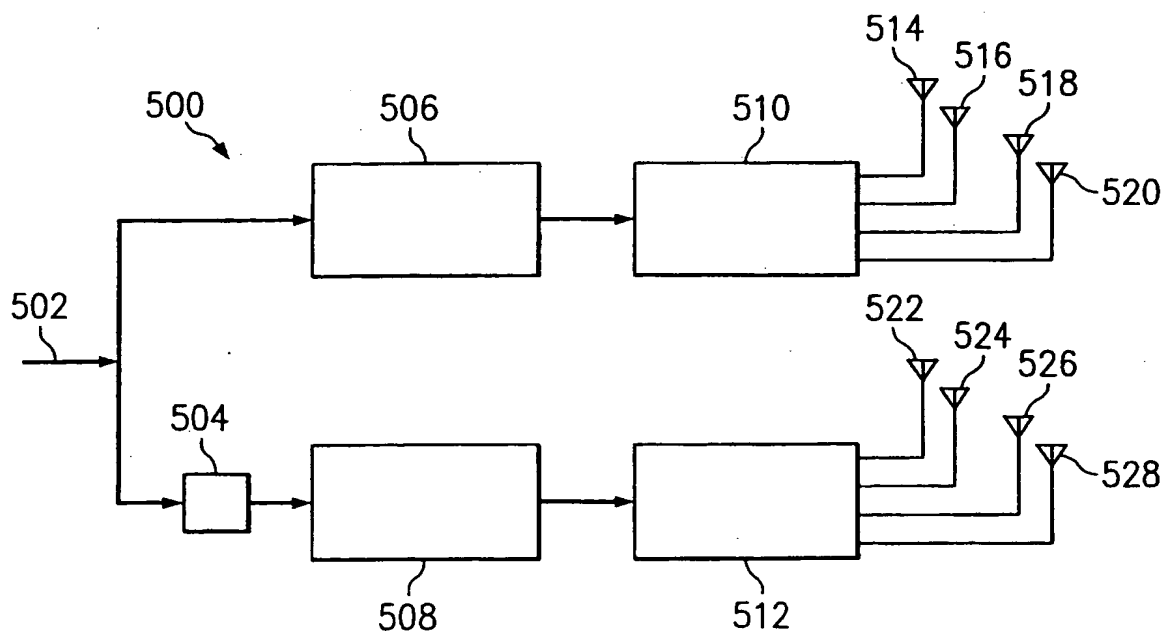


FIG. 5

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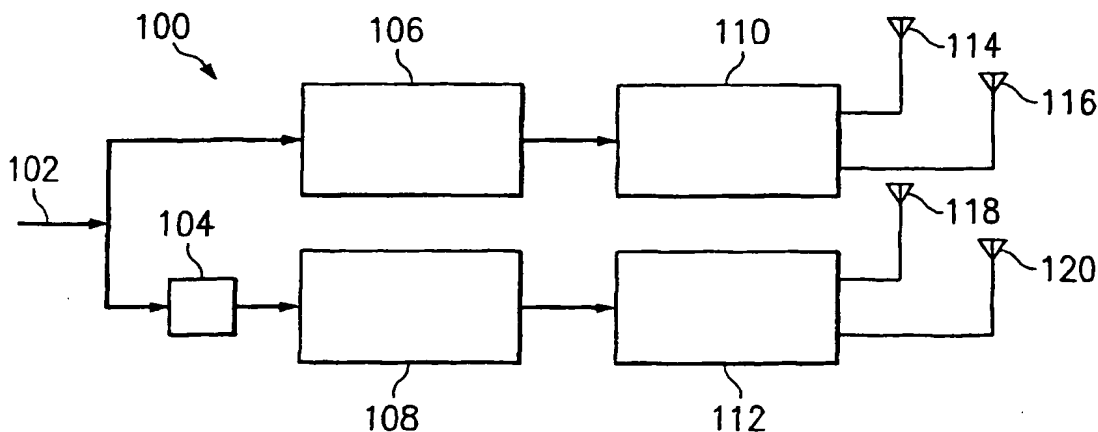
Published:

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(88) Date of publication of the international search report:
23 May 2002

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **SPACE-TIME CODE FOR MULTIPLE ANTENNA TRANSMISSION**



(57) Abstract: A method and apparatus for space-time coding signals for transmission on multiple antennas. A received input symbol stream is transformed using a predefined transform and transmitted on a first set of N antennas. The same input symbol stream is then offset by M symbol periods to generate an offset input symbol stream. The offset input symbol stream is then transformed using the predefined transform and transmitted on a second set of N antennas. A third through Xth set of N antennas may be utilized for transmission by successively offsetting the offset input symbol stream by an additional M symbol periods for each additional set of N antennas used, before performing the transform and transmitting on the additional set of N antennas.

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INTERNATIONAL SEARCH REPORT

Inter. Appl. No.
PCT/US 01/09983

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H04L1/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, WPI Data, PAJ, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 237 706 A (RACAL RES LTD) 8 May 1991 (1991-05-08) figure 9 page 16, paragraph 3 -page 17, paragraph 1 claim 5	1,13,25, 28
A	----- GUEY JIANN-CHING: "Concatenated coding for transmit diversity systems" PROCEEDINGS OF THE 1999 VTC - FALL IEEE VTS 50TH VEHICULAR TECHNOLOGY CONFERENCE 'GATEWAY TO 21ST CENTURY COMMUNICATIONS VILLAGE'; AMSTERDAM, NETH SEP 19-SEP 22 1999, vol. 5, 1999, pages 2500-2504, XP002181329 IEEE Veh Technol Conf; IEEE Vehicular Technology Conference 1999 IEEE, Piscataway, NJ, USA the whole document ----- -/-	1-30

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search 29 October 2001	Date of mailing of the international search report 16/11/2001
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Borges, P

INTERNATIONAL SEARCH REPORT

Inter. Application No

PCT/US 01/09983

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>ALAMOUTI S M: "A simple transmit diversity technique for wireless communications"</p> <p>IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE INC. NEW YORK, US, vol. 16, no. 8, October 1998 (1998-10), pages 1451-1458, XP002100058</p> <p>ISSN: 0733-8716</p> <p>cited in the application</p> <p>the whole document</p>	<p>1-8, 13-30</p>
A	<p>TAROKH V ET AL: "SPACE-TIME BLOCK CODING FOR WIRELESS COMMUNICATIONS: PERFORMANCE RESULTS"</p> <p>IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE INC. NEW YORK, US, vol. 17, no. 3, March 1999 (1999-03), pages 451-460, XP000804974</p> <p>ISSN: 0733-8716</p> <p>equations (6) and (7)</p>	<p>9-12</p>

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 1 (part), 13 (part)

Present claims 1 and 13 relate to an extremely large number of possible apparatus and methods. Support within the meaning of Article 6 PCT and/or disclosure within the meaning of Article 5 PCT is to be found, however, for only a very small proportion of the apparatus/methods claimed. In the present case, the claims so lack support, and the application so lacks disclosure, that a meaningful search over the whole of the claimed scope is impossible. Consequently, the search has been carried out for those parts of the claims which appear to be supported and disclosed, namely those parts relating to the apparatus/methods in which:

- Said transforms are space-time block codes and are the same for both symbol streams.
- The sets of antennas used for transmitting both streams are different.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/09983

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2237706	A	08-05-1991	NONE